STUDY OF NOTCH EFFECT ON THE MECHANICAL PROPERTIES OF MODERN GAS PIPELINE

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ABSTRACT

This paper presents analysis of different sizes of notch effect on the smooth tensile round bar of gas pipe by using finite element analysis for API X65 steel. The damage consider on the pipe is a third party accidents which means casual defect occurs after the fabrication or during the installation. Based on detailed finite element (FE) analyses the result stress strain curve compare among the notch radius of 6mm, 3mm, 1.5mm and also with smooth simulation model. The analysis carried on the high strength steel of API X70 and API X100 and compare with API X65. The result from the analysis is when the notch radius decreases yield and tensile strength increases but strain to the fracture decreases. The yield strength and tensile strength for the smooth and notch effect are greater for API X70 followed by API X100 compare with API X65.

Keywords: API X65, API X70, API X100 steels, Finite element (FE) analysis, Third party accident, Stress strain curve

ABSTRAK

Kertas ini mempersembahkan analisis bagi takuk yang berlainan ukuran atas gas paip API X65 dengan menggunakan perisian. Kemalangan pihak ketiga yang bermaksud kecacatan lalai berlaku selepas fabrikasi atau semasa pemasangan telah dipertimbangkan dalam kajian ini. Berdasarkan analisis, perbandingan di antara jejari 6mm, 3mm, 1.5mm dan juga bar bulat penuh dijalankan dengan menggunakan perisian. Selain itu, analisis yang dijalankan keluli kekuatan tinggi API X70 dan API X100 bandingkan dengan API X65. Hasil daripada analisis, didapati bahawa apabila jejari takuk berkurangan peningkatan kekuatan alah dan tegangan tetapi terikan patah berkurangan. Kekuatan alah dan kekuatan tegangan bagi bar licin dan takuk adalah lebih tinggi API X100 diikuti dengan API X70 dan terakhir adalah API X65.

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LIST OF SYMBOLS

C	Carbon
Mn	Manganese
Si	Silicon
Ni	Nickel
Cu	Copper
V	Vanadium
S	Sulphur
P	Phosphorus
US	Increases ultimate strength
P	Internal pressure
D	Outside diameter of the pipe
t	Normal wall thickness
σ	True Stress
ε	True Strain

LIST OF ABBREVIATIONS

FEA	Finite Element Analysis
ASME	American Society of Mechanical Engineers
NDE	Non Destructive Examination
FFP	Fitness for Purpose
BS	British Standards
API	American Petroleum Institute
SAW	Submerged Arc Welding
AS	Australian Standard
HAZ	Heat Affected Zone
GPa	Gigapascal
MPa	Megapascal
Mm	Milimeter

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CHAPTER 1

INTRODUCTION

1.1 Background Study

The pipeline transportation is the most economical and reasonable transport mode for long distance transportation of natural gas. The development of pipeline project is promoted by the increasing demand of petroleum and natural gas in the global. In order to enhance the transportation efficiency, reduce the energy consumption and save the investment, high strength pipe is developed for the tendency in the future. The pipelines transmitting natural gas may be subjected to plastic deformation by external forces such as ground subsidence, ground liquefaction bending and mechanical damage (Andrew Cosham et al., 2003). The effect of external loads on the pipeline can cause mechanical properties such as tensile strength, yield strength and fracture toughness differ from the straight pipes (J.-h. Baek et al., 2009). When any damage is present in a pipeline, proper engineering assessments are needed to determine whether pipelines are still fit for service.

The net sections limit load approach where a damaged pipe is assumed to fail at the load when the net section reaches a fully plastic state. That kind of approach is valid for a pipeline made of a material with sufficient ductility. In fact, the American Petroleum Institute (API) steels used extensively in gas pipelines are quite ductile and thus application of the net section limit load approach could be justified. Although the net section limit load approach is simple for practical application, validation is expensive as well as requiring a large number of full scale pipe test data. The more fundamental approach would be based on local failure criteria for ductile fracture. It has been shown that ductile fracture strongly depends on the stress state and can be effectively predicted using strain models incorporating the stress state effect (C.-K Oh et al., 2007).

In this study, the model of ductile fracture smooth and notched tensile bars with three different notch radii were analysed by using finite element analysis. Tensile tests were performed in Patran_Marc software by using smooth and notched round bars with three different notch radii. For the simulation, the first-order element which means the four-node quadrilateral element for two dimensional and axi-symmetric problems, only quarter of the part was simulated and analysed. The basic model of rectangular shape with the size of 25mm x 100m was simulated to analysis smooth bar. For notched bars, three different round notch radii were drawn which was 6.0 mm (6R), 3.0 mm (3R) and 1.5 mm (1.5R) and then analysed in Patran_Marc software. Based on the result stress strain curve was determined for the smooth and three type of the notch radius smooth bar. Then, the same method was applied and analysed by using difference type of material of API X70 and API X100. The final results of FE were analysed and discussed in the fourth chapter.

1.2 Problem Statement

The pipelines transmitting natural gas may be subjected damages by external forces due to environment and third party accidents. For example, land deformation or earth quake in Japan always cause damages on the gas pipe. In addition, the defect occurs due to third party accidents after the fabrication also may cause problems in long running usage. The high strength steel needs to be concerned to control ductile fracture of the pipe for long term. Nowadays, most the gas pipelines were integrated with high strength steel to make sure the ability of pipe resist damages. Hence, proper assessment was performed to determine the ability of defect pipe for the operation by using stress strain curve is a main key this study. The damage sizes on pipe were simplified as notch expression in this project.

1.3 Objective

a) To analyze different sizes of notch effect on the gas pipeline of API X65, API X70 and API X100
b) To compare variation of true stress strain curve for smooth and notch effect on for API X65, API X70 and API X100

1.4 Scope of Study

a) Study on the effect of mechanical properties of tensile strength, yield strength and stress strain curve variation for smooth and defect gas pipe. In this study, various sizes of notch effects were applied as defect on the pipe.
b) Assumed that no corrosion effect and burst effect on pipe.
c) The analysis performed using specimens were simulated from a pipe material API X65 and other material of API X70 and API X100 were used for comparison in this study.
d) The smooth and notched bar of three different radii of 6.0 mm (6R), 3.0 mm (3R) and 1.5 mm (1.5R) are performed in this study.
e) The gas pipe simulation is drawn in 3D dimension and failure analysis was carried by using Finite Element Analysis Patran_Marc software (FEA).

1.5 Expected Result

The different type of notch effect on the material will effect on the yield strength and strain to fracture. When the notch radius decreases, the yield and tensile strengths increase but the strain to fracture decreases. The yield and tensile strengths for smooth and notch effect pipe will be higher for API X70 and followed with API X100 compared API X65 steel.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In order to conduct analysis, it is important to review on the aspects that related to the field. Therefore, this chapter focusing on the fundamental of material, available standards for gas pipeline and parameters used to determine notch effect. In addition, the reviews on previous researches were very helpful for the analysis development.

2.2 Pipelines

The interstate natural gas pipeline network transports processed natural gas from processing plants in producing regions to those areas with high natural gas requirements by using buried pipeline. Geological changes such as surrounding movements can cause axial strain to the pipelines. Pipelines can be caused to strain by movements at the same level as the pipe such as soil instability during an earthquake, landslide or mudflow landing on the area of the line or mining subsidence. To overcome such problems, standards are defined to give maximum endurance of pipes. For example, Japanese standards have been defined for both temporary ground deformation such as seismic wave motion during an earthquake and permanent ground motion (Suzuki, N. and Toyoda, 2009).

Temporary ground deformation has been found to be limited to ±0.41 % which is less ground strain. The Japanese standards provide two levels of ground motions for larger permanent ground deformation. Level 1 is for the soil motion that occurs once or twice during the pipeline lifetime while the level 2 for very strong seismic motion due to earthquake which is occur at a low probability during the lifetime of gas pipelines. The pipe deformation of either ±1 % strain or 0.35 times the pipe thickness divided by the diameter as a nominal strain is considered the upper limit of Level 1 whereby the pipe should not be severely deformed. Pipeline deformation of ±3 % strain is considered the upper limit of Level 2 and also can apply for earthquake situations (Masuda, T. Et al., 2009).

Gas is mainly transport from one place to another place through under water of deep sea pipeline. The buckling resistance of the pipe under water is required to take consideration of external pressure on the pipe. So that, approximately 0.5 % plastic strain is to be considered for the deep sea gas pipeline design. Allowable span length is strain for concrete weight coating and the weight of covering mattresses used at small water depths which is less than 500 ft. This will protect the pipeline from hydrodynamic forces of waves or loads from fishing equipments when considerable static load to the pipeline in the vertical direction. Offshore pipelines tend to have thicker walls than onshore lines and often have a concrete coating to provide stability. Corrosion factor of pipeline for offshore need to consider to ensure endurance of pipeline (William Mohr, 2003).

2.3 Corrosion of Pipeline

Corrosion is an electrochemical process which is a time dependent mechanism and depends on environment to the pipeline. Corrosion causes metal loss whereby it may occur on the internal or external surfaces of the pipe, in the base of material the seam weld and the associated heat affected zone (HAZ). Internal and external corrosion are together one of the major causes of pipeline failures. Data for onshore gas transmission pipelines in Western Europe for the period from 1970 to 1997 indicates that 17 percent of all incidents resulting in a loss of gas were due to corrosion (Bolt,R., 1970-1997).

To avoid external corrosion on pipeline coatings are applied to provide a corrosion barrier and an abrasion barrier. Directional crossings generally encounter varying materials and often can be exposed to extra abrasion during the pullback. The coating should bond well to the pipe to resist soil stresses and have a smooth, hard surface to reduce friction and maintain the corrosion barrier. Protective coatings on pipeline can be done by electroplating, galvanising and metal spraying (E.W. McAllister, 2002).

Internal corrosion may be kept under control by establishing appropriate pipeline operating conditions and by using corrosion-mitigation techniques. One of method for reducing the potential for internal corrosion to occur is to control the quality of gas entering the pipeline. In addition, by periodically sampling and analyzing the gas, liquids, and solids removed from the pipeline to detect the presence and concentration of any corrosive contaminants (E.W. McAllister, 2002).

2.4 Materials

Material selection is very important for the gas pipeline based on the countries geology and weather. This is because to standardize proper materials used that can resist physical constraints on the pipes. So that, there are a lot of the standards established which used or adapt as reference in all over the world based on the their geological to make sure safe gas transmission in pipeline. For example, there are common standards used in gas pipeline material selection such as American Petroleum Institute (API), British Standard (BS), Australian Standard (AS) and so on. The mechanical properties and chemical properties of API X65, API X70 and API X100 in the table of 2.1 and 2.2.

Table 2.1: Mechanical Properties of APIX65, APIX70 and APIX100

Material	API X65[1]	API X70[2]	API X100[3]
Young's modulus (GPa)	210	210	210
Yield strength (MPa)	464.5	531	769
Tensile strength (MPa)	563.8	613	823
Yield/UTS	0.82	0.87	0.93
Chemical composition (types)	7	11	12

Source: C.-K. Oh et al., 2007[1], S.H. Hashemi[2], 2008 and S. H. Hashemi et al., 2004[3]

Table 2.2: Chemical Composition of APIX65, APIX70 and APIX100

Element (wt %)	API X65[1]	API X70[2]	API X100[3]
C	0.08	0.05	0.06
Si		0.21	0.18
Mn	1.45	1.5	1.84
P	0.019	0.008	0.008
S	0.03	0.015	0.001
Cu			0.31
Ni		0.187	0.5
Cr		0.01	0.03
Nb		0.05	0.05
Ti		0.019	0.018
Al			0.036
Co		0.003	
Fe	Balance		
Ceq	0.32		

Source: C.-K. Oh et al., 2007[1], S.H. Hashemi[2], 2008 and S. H. Hashemi et al., 2004[3]

API X65 steel is primarily used in the oil and gas industries as a pipe material because of strength and low cost. API X65 steel was commonly used in Iranian natural gas line project (JIA Zhi-xin et al., 1974). The yield strength API X65 steel is 464.5 MPa while tensile strength is about 563.8 MPa. The chemical composition is based on 7 types of materials which are C, P, Mn, S, Si, Fe and Ceq.

API X70 steel pipe is commonly used in Jining contact line of gas pipeline project from the west to the east of China (JIA Zhi-xin et al., 1974). The chemical composition is based on 11 types of materials which are C, Si, Mn, P, S, Ni, Cr, Mo, Nb, Ti and Co. So that, it shows high yield strength of 531MPa while tensile strength is about 5613 MPa.

API X100 steel pipes commonly used in offshore pipeline due to its high strength. The chemical composition is based on 12 types of materials which are C, Si, Mn, P, S, Cu, Ni, Cr, Mo, Nb, Ti and Al. Its yield strength is 769 MPa and tensile strength is 823 MPa. The ratio of yield to the ultimate tensile strength is 0.93.

All of the three materials consists young's modulus of 210 GPa. APIX 100 has high yield strength and tensile strength followed by APIX70 and APIX65. This is because chemical composition of APIX 100 is high whereby it consists of 12types of materials compare to other materials. APIX 70 shows second high chemical composition compare to API X65. So that, due to low chemical composition in APIX 65 which is only consists of 7 types of materials as well as gives lowest strength compare to the others materials.

2.4.1 Function of Chemical Composition:

- C, Carbon – Increases yield strength and ultimate tensile strength. It also increases hardness but reduces ductility and notch toughness as well as affects weld ability.
- Mn, Manganese – Deoxidizes and desulfurizes steel to refine the grain and improving hot workability. If ratio Mn/C>3, the Mn improves impact toughness and above 0.8% Mn tends to harden steel.
- Si, Silicon – Improves castability because Si is a deoxidizer that captures dissolved oxygen as well avoiding porosities.
- Ni, Nickel – Causes a significant improvement in fracture toughness and fatigue resistance.
- Cu, Copper – Improve atmospheric corrosion resistance.
- V, Vanadium – Refines steel grains and improving its mechanical properties.
- S, Sulphur –It is contained in the steel and is considered as an impurity that forms brittle crack prone iron sulfide.
- P, Phosphorus – Increases ultimate strength (US) of the steel. Otherwise it is considered an impurity because forms brittle and crack prone iron phospite during heat treatments or at high temperature services.

Source: (William Mohr.et.,al, 2003)

2.5 Pipeline Fabrication

Pipeline can be fabricated by using few type of method such as Helical or Spiral Welding, Longitudinal Welding using Submerged Arc Welding (SAW) and also Seamless process. Helical or Spiral Welding process consists of a coil of hot coiled plate is uncoiled, straightened, flattened and edges dressed. Then the plate is helical wound to form a pipe which its diameter depends of the width of the strip and the angle of coiling. After that, the helical internal seam is welded using (SAW) or inert gas as well as the seam and obtaining a continuous length of pipe when it is passed through a sequence of rollers to enhance circularity. Finally the pipe is tested using radiography or ultrasonic and also cut to the required lengths (Baró M.D, 2003).

The pipe is formed from individual plates of steel and subsequently applying U-O-E process in Longitudinal Welding using Submerged Arc Welding (SAW) process. Initially the edge of the plate is crimped into circular arcs over a width and end of each side is pressed between two shaped dies. Then, the plate is centred with the U-punch moves and bends the entire plate through three point bending. After that, the skelp is then conveyed to the O-press consisting of two semi-circular stiff dies which will forcing the skelp nearly into a circular shape. Finally, the skelp is welded and proceed with internal mandrel to lowering ovality of pipe (Baró M.D, 2003).

Seamless pipe is formed by hot working steel to form a pipe without a welded seam. This procedure can be done by different ways. The initially formed pipe may be subsequently cold worked to obtain the required diameter and wall thickness when heat treated to modify the mechanical properties. To obtain the pipe, a solid steel bar is firstly drilled from a slab and is heated in order formed by rollers around a piercer to produce the length of the pipe.

Higher cost is needed become a disadvantage for this procedure although it will consume a lot of time. In addition, wide variation of wall thickness cause out of roundness and straightness to the physical of pipe (Baró M.D, 2003).

2.6 Pipeline Pressure

Gas flowing from higher to lower pressure is the fundamental principle of the natural gas delivery system. The amount of pressure in a pipeline is measured in pounds per square inch. Internal and external pressure in gas pipeline plays very important role in gas transporting as well as damages on the pipes.

2.6.1 Internal Pressure

The circular pipe is subject to internal pressure the pipe material at any point will have two stress components at right angles to each other. The larger of the two stresses is known as the hoop stress and acts along the circumferential direction. Hence, it is also called the circumferential stress. The other stress is the longitudinal stress also known as the axial stress which acts in a direction parallel to the pipe axis. Figure 2.5.1 shows cross section of a pipe subject to internal pressure. An element of the pipe wall material is shown with the two stresses S_h and S_a in perpendicular directions. Both stresses will increase as the internal pressure is increased. Hoop stress is inversely proportional to thickness of pipe wall (E. Shashi Menon, 2005). Internal pressure increases resistance to local buckling because the tensile hoop stress which creates condition for the pipe to resist the diametrical changes that occur locally at the buckle (William Mohr, 2003). The stresses in pipe subjected to the internal pressures are shown in the Figure 2.1 below.

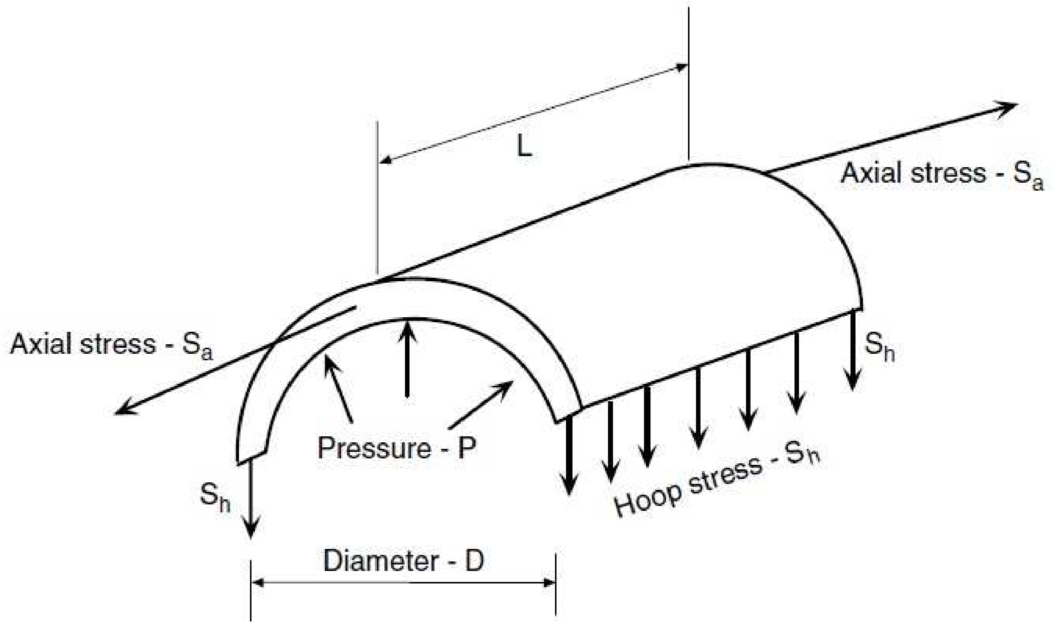

Figure 2.1: Stresses in Pipe Subjected to Internal Pressure

Source: E. Shashi Menon , 2005

2.6.2 External Pressure

External pressure can result from the weight of the soil above the pipe in a buried pipeline and also by the loads transmitted from vehicular traffic in areas where the pipeline is located below roads, highways, and railroads. The deeper pipe is buried there will be a higher soil load on the pipe. However, the pressure transmitted to the pipe due to vehicles above ground will diminish with the depth of the pipe below the ground surface. Thus, the external pressure due to vehicular loads on a buried pipeline that is 6 ft below ground will be less than that on a pipeline that is at a depth of 4 ft. In most cases involving buried pipelines which transporting gas the effect of internal pressure is more than that of external loads. Therefore, the necessary minimum wall thickness will be dictated by the internal pressure in a gas pipeline. So that, higher strength steel pipes will require less wall thickness to withstand the given pressure compared to low-strength materials (E. Shashi Menon, 2005).

2.7 Gas Pipeline Leakage Detection

Most of the long-distance modern pipelines are operated automatically by using computer systems. With the aid of computer systems operators can monitors the pressure, flow rates, and other parameters at various locations along the pipe as well as can sends commands to the field to control the operation valves and pumps. Manual intervention is frequently needed to modify the automatic operation when different of fuels are directed to different temporary storage tanks or when the system must be shut down. The pipeline will be fitted with some type of leak detection system which will be response when the pipeline failed. There are various types of systems to determine of gas pipeline leakage (Phil Hopkins, Penspen Ltd, 2002).

The simple method is by looking for evidence of discoloured vegetation around the pipeline and also hearing or smelling.

The flow balance method involves measuring inputs and outputs of a pipeline. A loss of product is determined by the difference between the steady state of the system at the instantaneous inlet and outlet flows.

Acoustic method is commonly used in leakage detection of the pipeline. Noise associated with a leak can be detected. Transducers can be clamped to a pipeline and by noting signal strength the source of the leak can be pinpointed by accessing leakage frequencies.

Detection and location of leaks can found by using real time pipeline modelling which simulates the operation of the pipeline and compares the expected with the actual values. The model is a mathematical representation of the pipeline and will include such features as elevation data, valve and pump locations and so on. The model can calculate the expected pressures, flows and so on as well as compare them with the measurements shown. If found any leakage the leak alarms can be triggered.